NBS

Technical Note No. 226

AN ATLAS OF VLF EMISSION SPECTRA OBSERVED WITH THE "HISS RECORDER"

By

Jean A. Koch and V. Christine Edens

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its four Institutes and their organizational units.

Institute for Basic Standards. Electricity. Metrology. Heat. Radiation Physics. Mechanics. Applied Mathematics. Atomic Physics. Physical Chemistry. Laboratory Astrophysics.* Radio Standards Laboratory: Radio Standards Physics; Radio Standards Engineering.** Office of Standard Reference Data.

Institute for Materials Research. Analytical Chemistry. Polymers. Metallurgy. Inorganic Materials. Reactor Radiations. Cryogenics.** Office of Standard Reference Materials.

Central Radio Propagation Laboratory.** Ionosphere Research and Propagation. Troposphere and Space Telecommunications. Radio Systems. Upper Atmosphere and Space Physics.

Institute for Applied Technology. Textiles and Apparel Technology Center. Building Research. Industrial Equipment. Information Technology. Performance Test Development. Instrumentation. Transport Systems. Office of Technical Services. Office of Weights and Measures. Office of Engineering Standards. Office of Industrial Services.

---

* NBS Group, Joint Institute for Laboratory Astrophysics at the University of Colorado.
** Located at Boulder, Colorado.

NATIONAL BUREAU OF STANDARDS

Technical Note 226

Issued November 13, 1964

AN ATLAS OF VLF EMISSION SPECTRA OBSERVED WITH THE "HISS RECORDER"

by

Jean A. Koch and V. Christine Edens
Central Radio Propagation Laboratory
National Bureau of Standards
Boulder, Colorado

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D.C. 20402

An Atlas of Very-Low-Frequency Emission Spectra Observed with the "Hiss Recorder"

Jean A. Koch and V. Christine Edens

Central Radio Propagation Laboratory
National Bureau of Standards, Boulder, Colorado

Foreword

Several catalogs of VLF emission spectra have been published in recent years. In all cases the data were taken using a technique established for the IGY in which the VLF signal from a loop or long wire antenna was amplified and recorded on magnetic tape for two minutes of an hour [Helliwell and Carpenter, 1961]. Some unusual VLF emissions, particularly those following whistlers, were presented by Dinger in 1956. In 1957 the VLF emissions were classified into types which were quite reproducible by Gallet and Jones. An extensive collection of these classes of emissions was published by Jones, Gallet, Watts, and Frazer [1963]. This compilation which was composed of numerous sonagrams of data recorded at Boulder, Colorado, from 1957 to 1959, illustrated the frequency-time spectrum of the classes of individual emissions known at that time. Each sonagram contained 2.4 seconds of VLF activity, and, for some events, several

sonagrams were connected to cover the activity for as much as two minutes. In 1962 an atlas was published by Helliwell, Katsufrakis, Marks, Reed and Trimpi in which the VLF emission activity at a high latitude station (Byrd, Antarctica, L = 6.8) was presented. Continuous spectrum recordings which contained about 100 seconds of data recorded at 35 minutes past the hour were presented for a number of days from May 1959 to May 1960. It was shown that at a high latitude hiss and chorus were present during many hours of the day.

The recordings of Jones, et al., and Helliwell, et al., showed that the discrete VLF emissions (chorus, hooks, risers, tones, etc.) usually did not occur singly, but in related groups which often lasted longer than the two-minute recording period. It became apparent from the catalogs that more comprehensive data were needed to understand the morphology of VLF emissions.

In 1960 an instrument called a "hiss recorder" was developed for continuous observation of VLF emissions [Watts, Koch and Gallet, 1963]. The time resolution of the instrument was such that long-term (several hour) rather than short-term (few second) fluctuations of the emissions are observed. The present atlas, which is based on these continuous hiss recorder observations, may be considered a sequel to the previous atlases in the sense that it extends the classification from types of individual VLF emissions to types of long-term groups of emissions. With this data it is now possible to observe the morphology of periods of VLF activity and to compare such events with other geophysical phenomena.

The purpose of this atlas is to present a representative selection of long-term activity. While classifications of the different types are made, no quantitative discussion of the source of these groups of emissions is given. The term "VLF emission event" will be restricted in this report to groups of emissions which last for at least 15 seconds, since this is the shortest period which can be easily observed by the hiss recorder.

The observations are organized into four sections corresponding to four characteristics of the morphology of VLF emission activity. These are

1. VLF emission events rising in frequency (page 4)
2. Simultaneous observations at several locations (page 9)
3. Simultaneous observations at conjugate points (page 14)
4. Long period pulsations (page 19).

1. "RISING" VLF EMISSION EVENTS

Not long after the hiss recorder began continuously monitoring the VLF activity it was noted that the long duration VLF events sometimes rose in frequency. In these cases the whole frequency band of emissions rose several kilocycles per second. The events usually end at the maximum frequency attained, although sometimes the upper frequency fluctuates throughout the duration of the event. Numerous rising VLF events have been recorded over a range of latitudes and longitudes. It is now apparent that the rise in frequency is a general characteristic of the VLF activity which occur most frequently at middle geomagnetic latitudes corresponding to $L \simeq 2$ to 4 (L is McIlwain's parameter that defines the shells on which particles drift) [McIlwain, 1961].

Individual VLF emissions, which reappear several times within a two-minute recording period and occur at successively higher frequencies with each appearance, have been previously observed in the high resolution magnetic tape data [Pope and Campbell, 1960]. However, while these individual emissions rise in a period of from a few seconds to a minute, the VLF emission events reported here often continue to rise in frequency over a period of hours.

Figure 1.1 First observed case of rising hiss.

On 16 February 1962 a band of VLF emissions was observed to rise in frequency at Minneapolis (L = 3.2). This event is composed of a band of hiss in which the lowest frequency rose from 2 to 7 kc/s within 90 minutes. (The four horizontal bands above 12 kc/s are VLF code stations.)

(IN ALL HISS RECORDER RECORDS THE TIME INCREASES FROM RIGHT TO LEFT.)

Figure 1.1

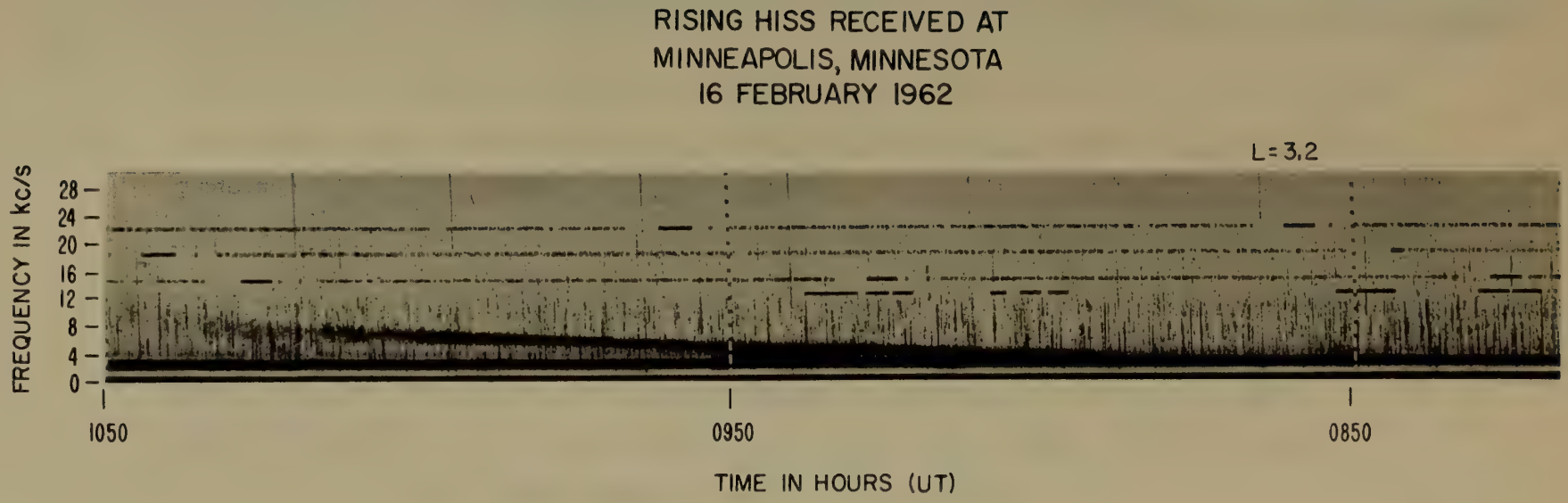

RISING HISS RECEIVED AT
MINNEAPOLIS, MINNESOTA
16 FEBRUARY 1962
L=3.2
FREQUENCY IN kc/s
28
24
20
16
12
8
4
0
1050
0950
0850
TIME IN HOURS (UT)

Figure 1.2

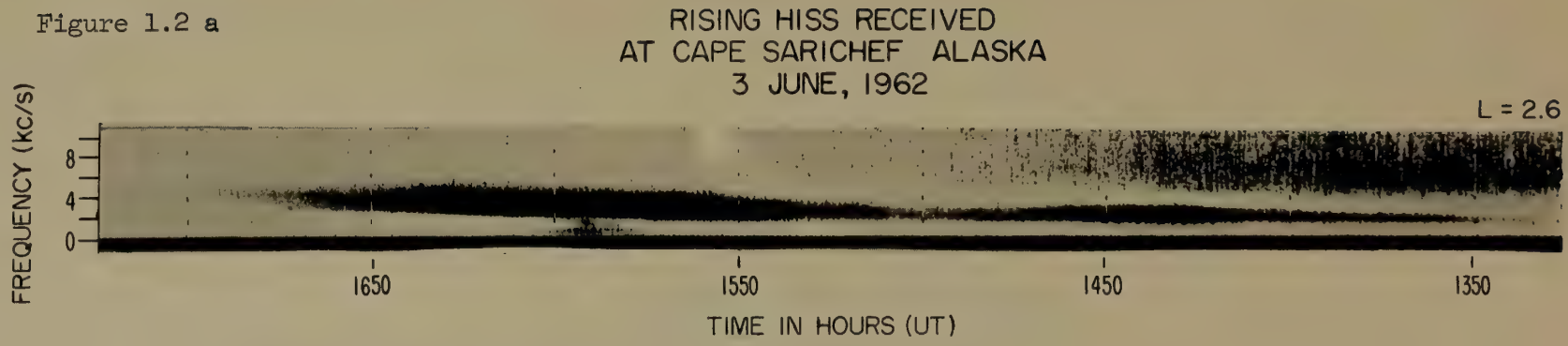
a. Rising hiss fluctuating in frequency.

The upper frequency level of the band of hiss recorded at Cape Sarichef, Alaska on 3 June 1962 rose about 1 kc/s from 1350 UT to 1450 UT, decreased for about an hour and then rose 2 kc/s from 1520 UT to 1650 UT.

b. Abrupt rise in frequency and sharp cutoff.

The upper frequency band of hiss recorded at Waimate, New Zealand on 3 September 1962 rose abruptly at the beginning of the event (1 kc/s within 7 minutes) and then the entire band rose 2 kc/s from 1250 UT to 1340 UT and cutoff sharply. These stations are at magnetically conjugate points on the shell L = 2.6. In each case the rising hiss event had the same spectral shape at the conjugate station.

Figure 1.2 a



1.2 b

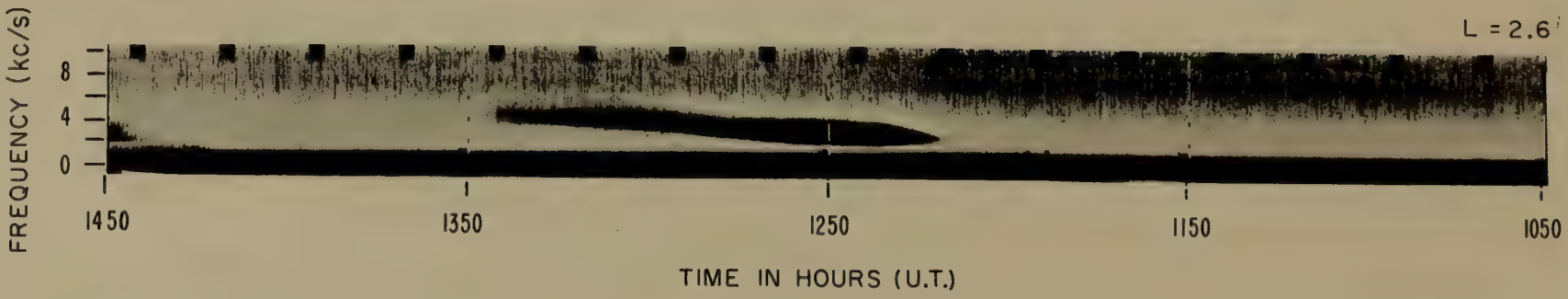


Figure 1.3 Rising hiss and discrete emissions extending over a wide frequency band.

At Minneapolis on 11 April 1964 two bands of emissions rose in frequency over a period of two hours. At 1050 UT the event was composed of hiss, chorus and hooks. The hiss extended from 2 to 6 kc/s and the discrete emissions were centered around 4 kc/s. By 1150 UT the hiss had risen 3 kc/s, to extend from 5 to 9 kc/s, and the discrete emissions were present between 4 and 5 kc/s.

Figure 1.3

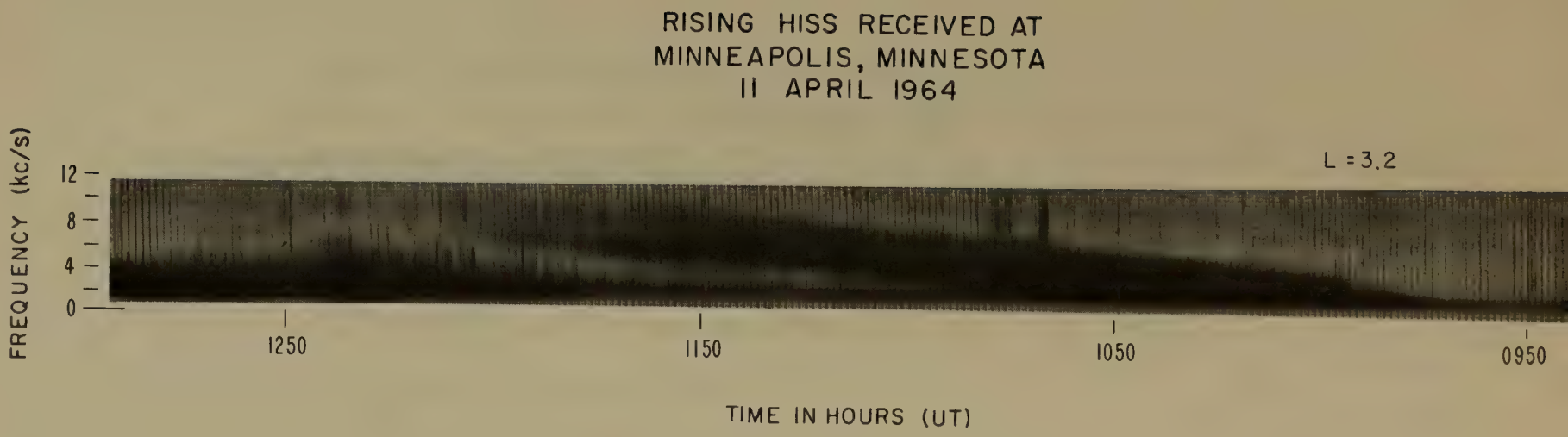
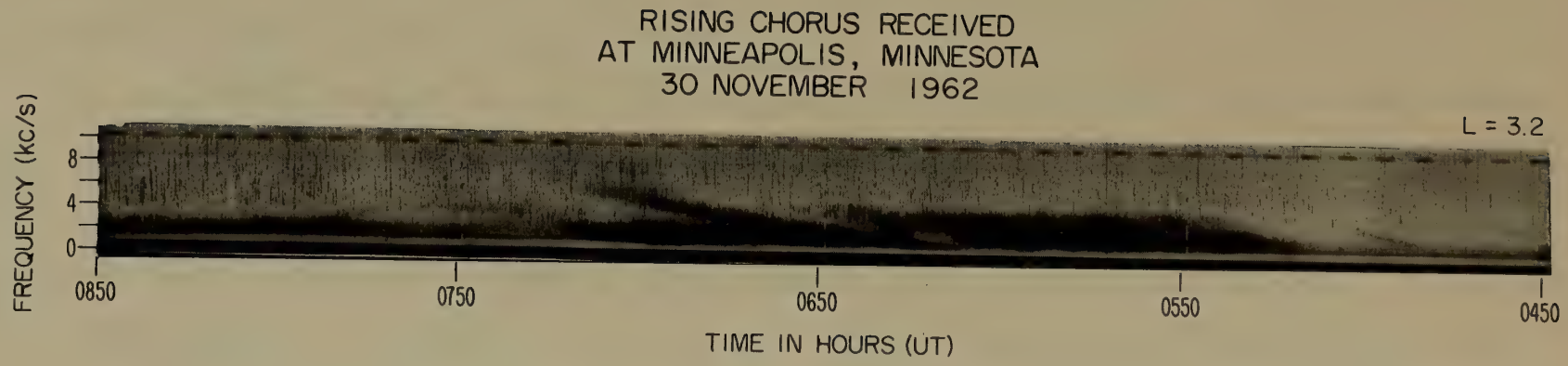

RISING HISS RECEIVED AT
MINNEAPOLIS, MINNESOTA
11 APRIL 1964
L = 3.2
FREQUENCY (kc/s)
12
8
4
0
1250
1150
1050
0950
TIME IN HOURS (UT)

Figure 1.4 Rising chorus.

While nearly all rising VLF events are composed at least partly of non-discrete hiss, a few, as in this example, have been found to consist solely of chorus (discrete bursts of VLF noise lasting a few tenths of a second). The chorus is distinguished by examination of the high resolution magnetic tape recordings made at 50 minutes past the hour. In this case, recorded at Minneapolis on 30 November 1962, part of a band of chorus rose 3 kc/s between 0700 and 0735 UT.

Figure 1.4


RISING CHORUS RECEIVED
AT MINNEAPOLIS, MINNESOTA
30 NOVEMBER 1962
L = 3.2
FREQUENCY (kc/s)
8
4
0
0850
0750
0650
0550
0450
TIME IN HOURS (UT)

2. VLF EMISSION EVENTS RECEIVED SIMULTANEOUSLY AT SEVERAL LOCATIONS

Individual VLF emissions have previously been found to occur simultaneously at stations separated by great distances in the northern hemisphere. This large effective area of reception is usually attributed to propagation between the earth and the ionosphere.

With hiss recorders placed at a number of locations, it has been noted that the entire VLF emission event may also be received simultaneously at widely spaced stations. These simultaneous occurrences show similar structure and are almost always observed during magnetically disturbed periods. However, there are usually small differences superimposed on the otherwise identical features of the event. For instance, while interruptions in an event may occur for the same length of time at all the stations, the activity may extend over a broader frequency range at one of them. For some events only a part of the activity is present at one station. In other cases, the VLF activity occurs alternately.

Figure 2.1 Fifteen-minute burst of chorus and hiss received simultaneously on hiss recorders at seven stations.

This "world-wide" occurrence of VLF emissions on 27 September 1963 was coincident in time with the sudden commencement at 1942 UT. The burst was received with the same structure at the conjugate stations, Baie St. Paul, Quebec, and Eights, Antarctica, as well as at Minneapolis and Byrd, Antarctica. The burst was much less evident at the lower latitude conjugate stations, Cape Sarichef, Alaska, and Waimate, New Zealand. The hiss recorder at Great Whale River, Quebec, which is conjugate to Byrd, Antarctica, was not operating at this time but part of the event was recorded on magnetic tape during the 1950 UT run. There was a magnetic storm from 27 September 1942 UT to 30 September 03xx UT.

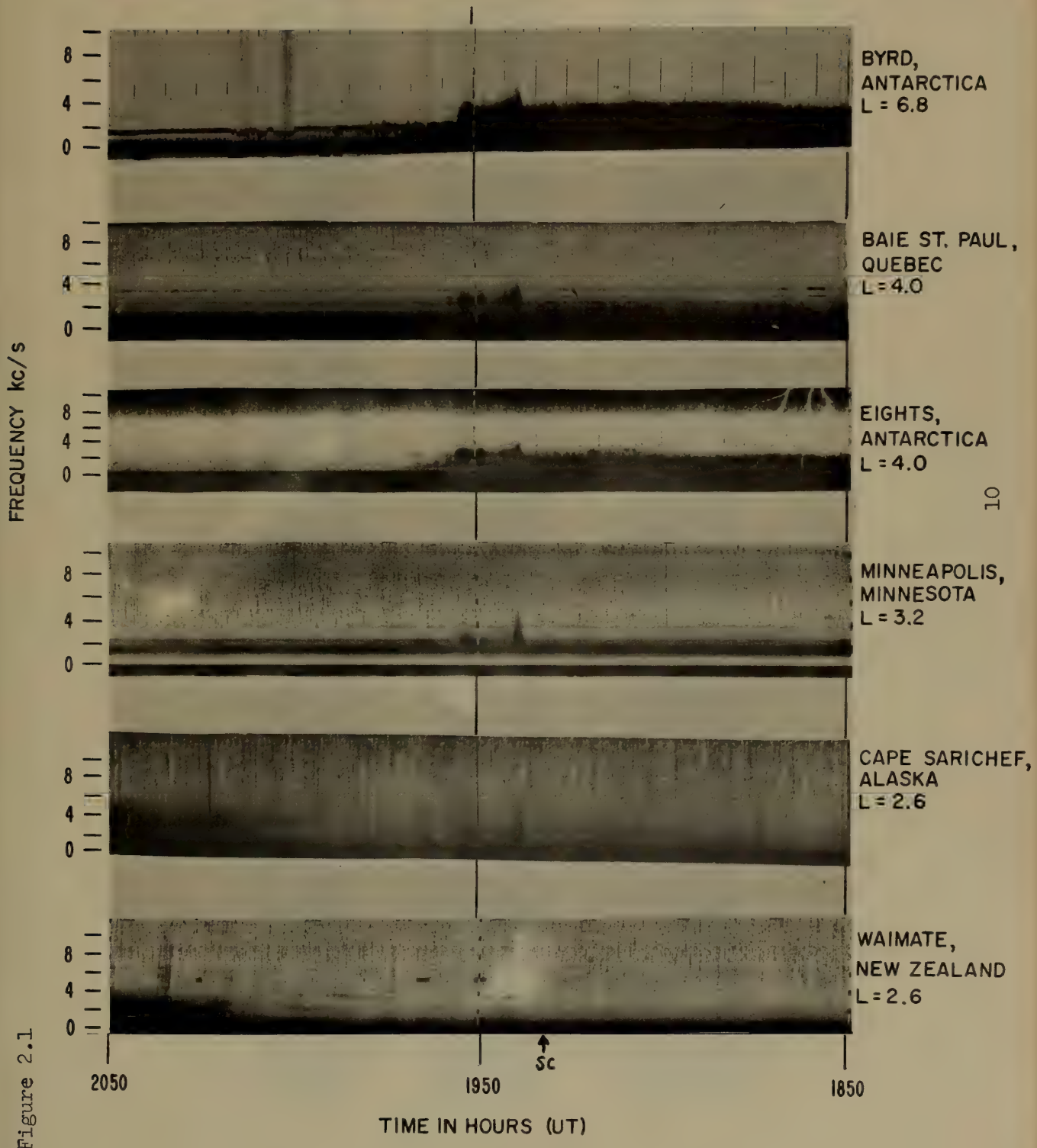

27 SEPTEMBER 1963
FREQUENCY kc/s
8
4
0
BYRD, ANTARCTICA L = 6.8
BAIE ST. PAUL, QUEBEC L = 4.0
EIGHTS, ANTARCTICA L = 4.0
MINNEAPOLIS, MINNESOTA L = 3.2
CAPE SARICHEF, ALASKA L = 2.6
WAIMATE, NEW ZEALAND L = 2.6
SC
2050
1950
1850
TIME IN HOURS (UT)

Figure 2.1

Figure 2.2 Interruptions in event received simultaneously at three stations.

In this example, hiss and chorus were received with simultaneous interruptions at three stations in the northern hemisphere. While the same interruptions were apparent in the records from all three locations, they are better defined at the highest latitude, Baie St. Paul. This simultaneity in the event could indicate that the interruptions either happened above the ionosphere, or occurred in the ionosphere at one place, and then propagated in the earth-ionosphere waveguide to each receiver. There was a magnetic storm from 9 February 2102 UT to 13 February 22xx UT.

Figure 2.2

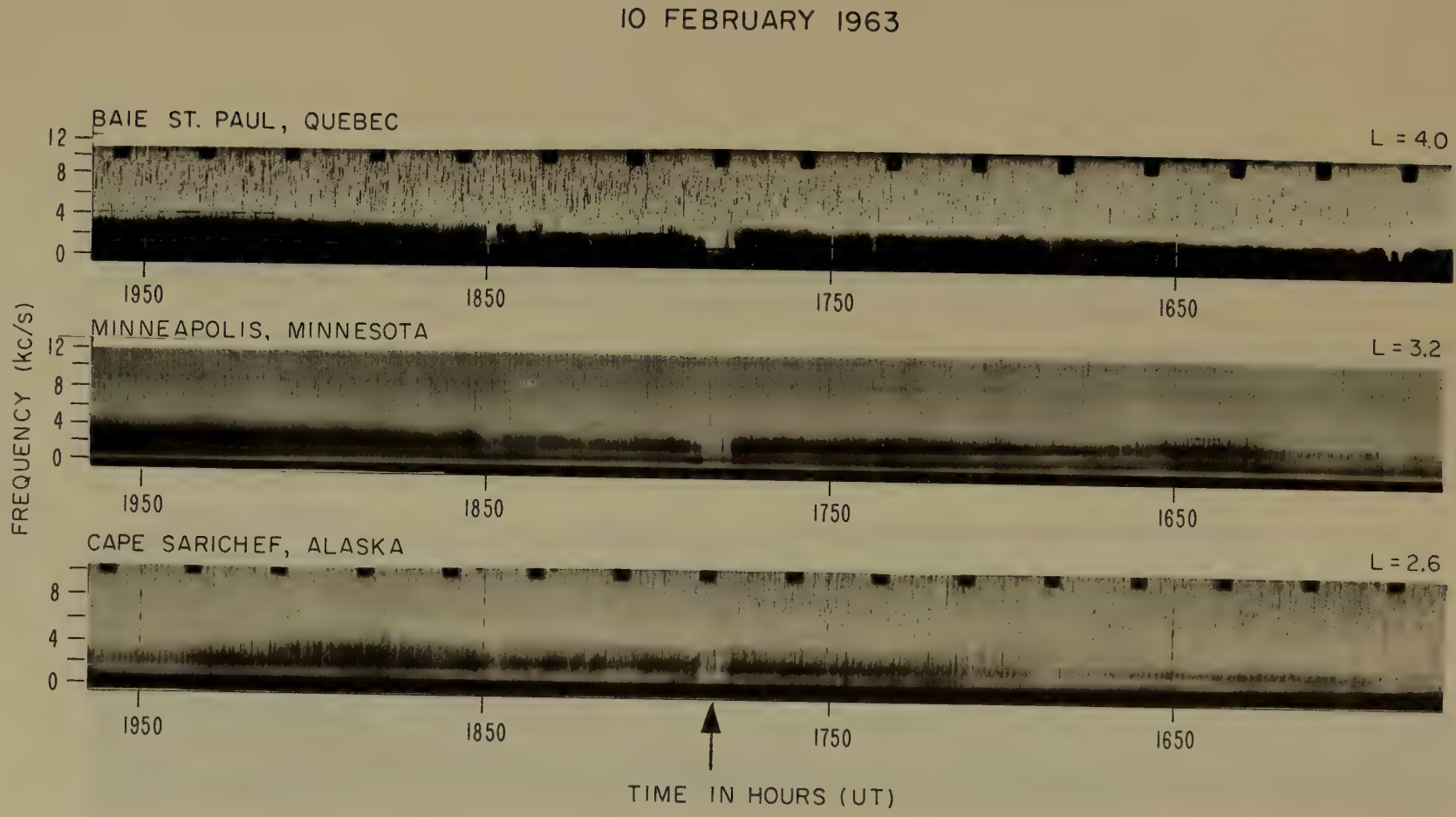

10 FEBRUARY 1963
BAIE ST. PAUL, QUEBEC
L = 4.0
MINNEAPOLIS, MINNESOTA
L = 3.2
CAPE SARICHEF, ALASKA
L = 2.6
FREQUENCY (kc/s)
12
8
4
0
1950
1850
1750
1650
TIME IN HOURS (UT)

Figure 2.3 Hiss and chorus received simultaneously at four stations.

The fluctuations in frequency and interruptions in the event received on 22 September 1963 appeared simultaneously at all the stations, although the emissions covered a broader frequency range at Byrd and Minneapolis. There is a great similarity in the event received at the magnetically conjugate stations, Baie St. Paul and Eights. A striking similarity is also evident in the emissions received at Minneapolis and Byrd. While Byrd is higher in latitude, it is close to the same magnetic longitude as the conjugate point for Minneapolis. The emissions seen at these two stations are often similar. There was a magnetic storm from 21 September 1414 UT to 23 September 22xx UT.

Figure 2.3

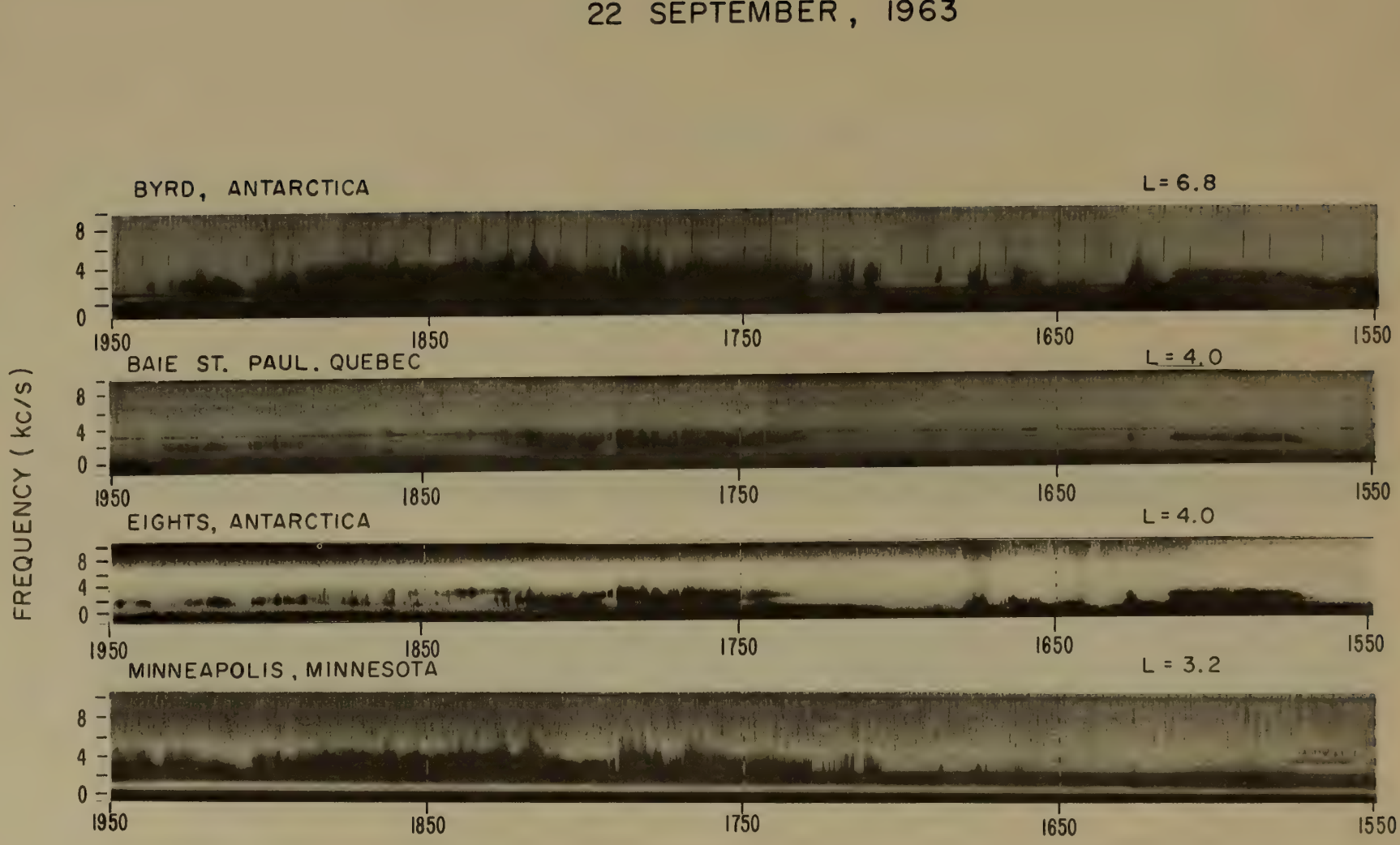
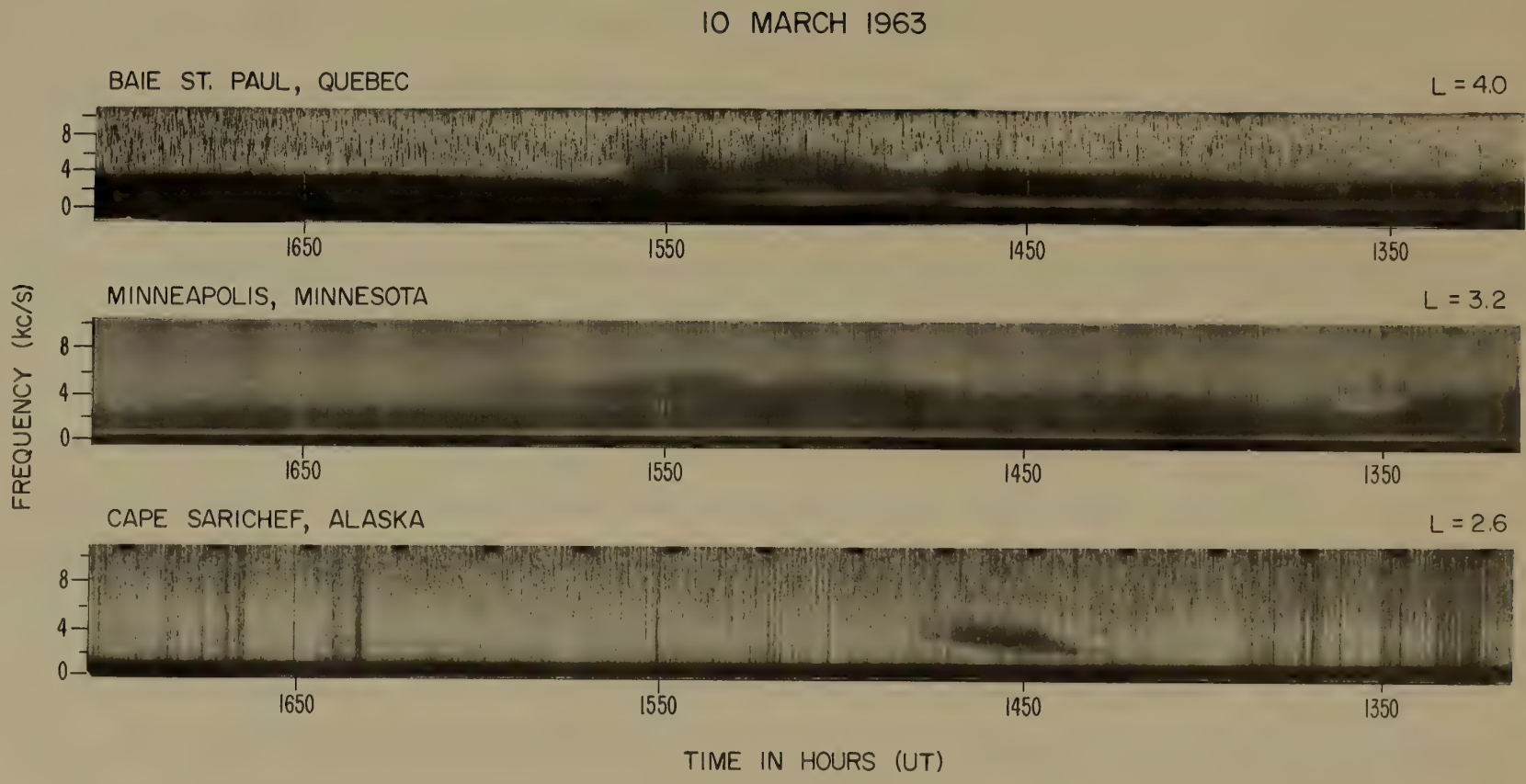

22 SEPTEMBER, 1963
BYRD, ANTARCTICA
L = 6.8
BAIE ST. PAUL, QUEBEC
L = 4.0
EIGHTS, ANTARCTICA
L = 4.0
MINNEAPOLIS, MINNESOTA
L = 3.2
FREQUENCY (kc/s)
8
4
0
1950
1850
1750
1650
1550
TIME IN HOURS (UT)

Figure 2.4 Simultaneous events with different shapes.

Unlike the three previous figures, these simultaneous events do not have the same general shapes nor the same duration. It is more common, however, for the events to be quite similar during a magnetically disturbed period. The hiss and chorus exhibit some of the same characteristics at Baie St. Paul and Minneapolis but not at Cape Sarichef. There was a magnetic storm from 7 March 21xx to 11 March 05xx UT.

Figure 2.4


10 MARCH 1963
BAIE ST. PAUL, QUEBEC
L = 4.0
MINNEAPOLIS, MINNESOTA
L = 3.2
CAPE SARICHEF, ALASKA
L = 2.6
FREQUENCY (kc/s)
8
4
0
1650
1550
1450
1350
TIME IN HOURS (UT)

3. VLF EMISSION EVENTS RECEIVED SIMULTANEOUSLY AT CONJUGATE POINTS

While the mechanism of generation of VLF emissions is not known, evidence indicates that the cause lies in particles trapped by the lines of force of the earth's magnetic field. After emission, a VLF electromagnetic wave propagates along the lines of force to the ground. In some cases, the reflected "echo" of the wave is observed in the opposite hemisphere at the magnetically conjugate point with a delay of one to two seconds.

Hiss recorders were placed at conjugate stations in 1961 in order to continuously observe VLF activity in the two hemispheres. It has been found that with few exceptions, the long-term groups of emissions occur simultaneously at the conjugate stations. While some of the fine details of the event may be different, the general spectral shape and duration of the entire event are quite similar.

Recently, a number of observations have been made at conjugate points which indicate that phenomena due to particle precipitation such as the aurora and radio wave absorption are observed simultaneously at conjugate points [Anderson, et al., 1962; Hook, 1962; Little, et al., 1964; Leinbach and Basler, 1963]. Since there is evidence for an association between some types of VLF emissions, auroral activity and D-region absorption, it may be inferred that some simultaneous conjugate VLF emission events are the result of particl precipitation in the two hemispheres.

Figure 3.1 Five hours of simultaneous hiss at conjugate points.

Hiss rising in frequency was observed simultaneously at the conjugate stations Cape Sarichef, Alaska, and Waimate, New Zealand, on 27 October 1962. The spectral shape of the event was quite similar in the two hemispheres with the fluctuations occurring simultaneously. The center frequency of the hiss rose 3 kc/s within 5 hours.

Figure 3.1

RISING HISS RECORDED AT
CONJUGATE POINTS
27 OCTOBER 1962

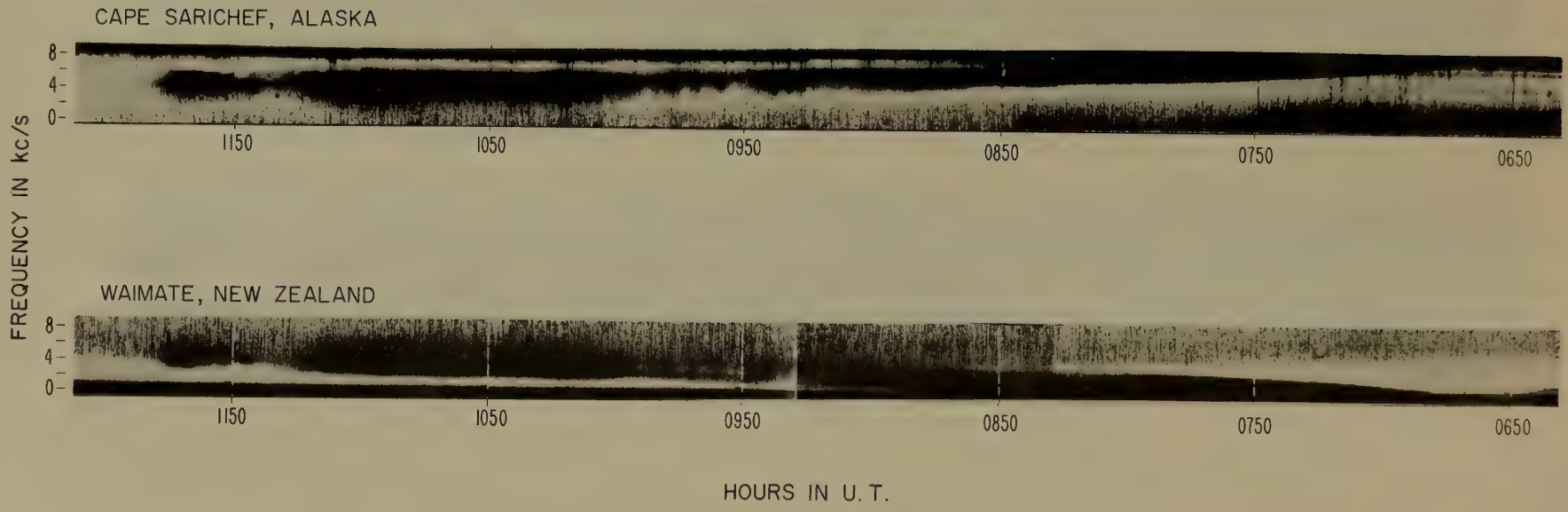


Figure 3.2 Hiss and chorus recorded simultaneously at conjugate points with slightly different spectral shapes.

The event recorded at Cape Sarichef, Alaska, and Waimate, New Zealand, on 22 September 1962 had some differences in the spectral shapes received at the two stations. Both stations recorded VLF emissions in two frequency bands centered at 2 and 3 kc/s, however, the bands are more discrete in frequency in the South. The event also began several minutes earlier at the New Zealand station.

Figure 3.2

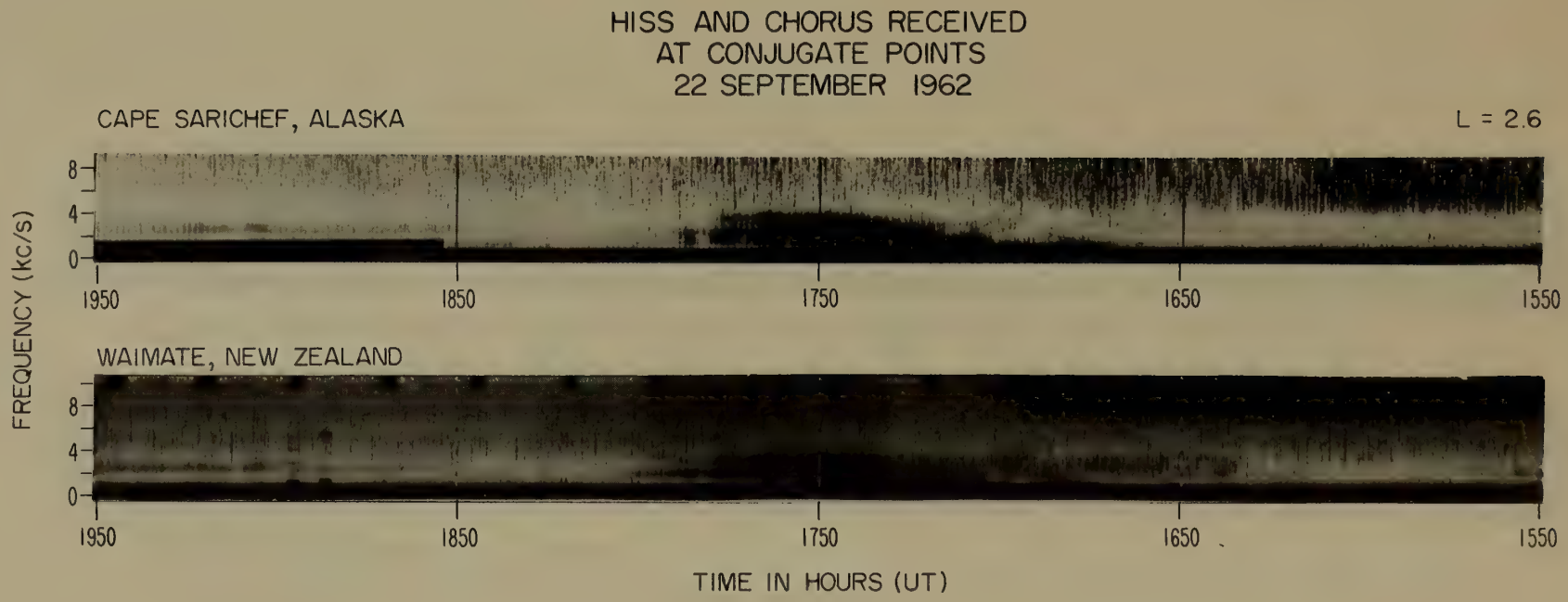

HISS AND CHORUS RECEIVED
AT CONJUGATE POINTS
22 SEPTEMBER 1962
CAPE SARICHEF, ALASKA
L = 2.6
WAIMATE, NEW ZEALAND
FREQUENCY (KC/S)
8
4
0
1950
1850
1750
1650
1550
TIME IN HOURS (UT)

Figure 3.3 Bursts of hiss and chorus received simultaneously at conjugate stations.

Hiss and chorus were received in bursts which lasted from several minutes to more than one hour at Baie St. Paul, Quebec, Canada, and Eights, Antarctica, on 5 January 1964. The duration and structure of each burst is quite similar in both hemispheres. (The calibration marks at 50 minutes past the hour do not coincide in time at both stations due to a mistake in programming the equipment at Eights. The records are aligned in time.)

Figure 3.3

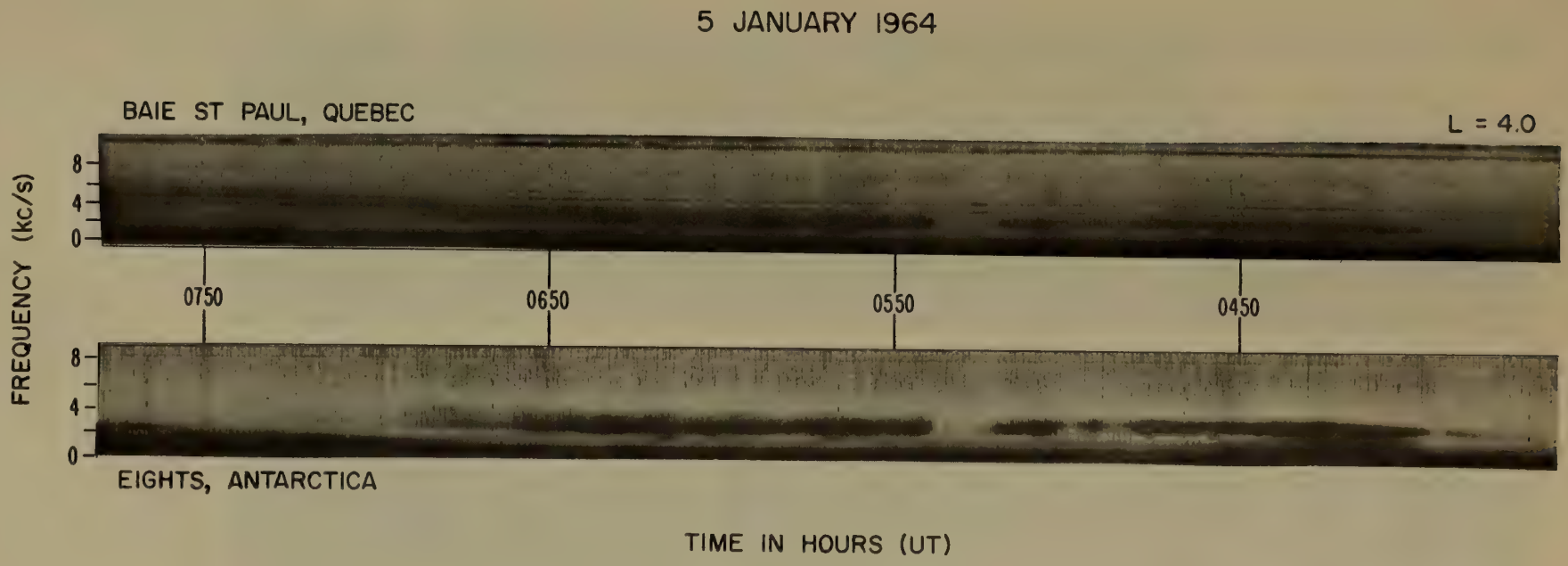

5 JANUARY 1964
BAIE ST PAUL, QUEBEC
L = 4.0
8
4
0
0750
0650
0550
0450
8
4
0
EIGHTS, ANTARCTICA
FREQUENCY (kc/s)
TIME IN HOURS (UT)

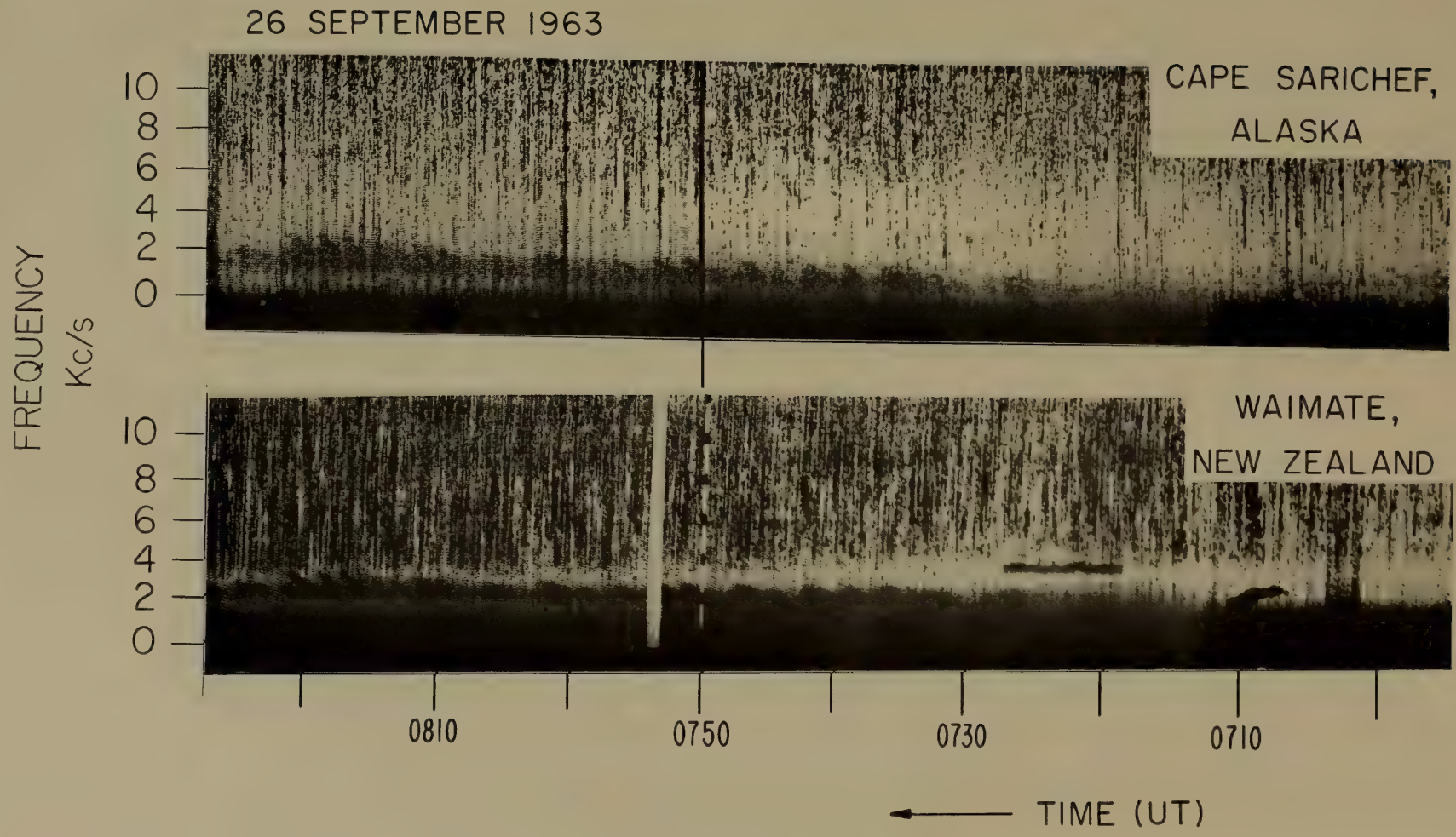
Figure 3.4 VLF pulsations recorded at conjugate points.

On 26 September 1963 hiss was observed to occur in bursts of two minutes and at intervals of five minutes at the conjugate stations, Cape Sarichef, Alaska, and Waimate, New Zealand. These bursts were found to be in phase between the two hemispheres in contrast with the periodic emissions, reported previously, which were of a few seconds duration and alternated between hemispheres. The longer duration periodic VLF emissions illustrated in this figure belong to a new class of VLF emission phenomena which we have called VLF pulsations. They are discussed in the following section.

VLF PULSATIONS
RECEIVED SIMULTANEOUSLY AT CONJUGATE POINTS

Figure 3.4

L=2.6



4. LONG PERIOD PULSATIONS

Periodic VLF emissions which consist of short bursts of noise occurring at regular intervals have previously been observed in the data taken on magnetic tape [Dinger, 1957; Pope and Campbell, 1960; Lokken, et al., 1961; Brice, 1962]. The periodicity which is of the order of a few seconds has been attributed to mirroring bunches of particles or to triggering by VLF waves [Helliwell, 1963; Brice, 1963].

The time resolution of the hiss recorder has allowed the observation of another periodicity in VLF emission activity [Watts, Koch and Gallet, 1963]. Whereas the magnetic tape has recorded pulsations with periods of a few seconds, hiss recorders have observed VLF pulsations with 20 to more than 250-second periods. While the short duration periodic emissions occur alternately at conjugate points, the long period pulsations are received simultaneously.

Figure 4.1 Long period VLF pulsations recorded at a low latitude station.

These pulsations were received at Cape Sarichef, Alaska on 21 May 1962 (L = 2.6). At 1450 UT the detailed structure of four of the pulsations was recorded on magnetic tape. The pulsations are composed of hiss and rising tones with a period of 45 seconds. (In these examples, the mirror image of the hiss recorder record is presented in order that the time scales of the two records increases in the same direction.)

Figure 4.1

VLF PULSATIONS RECEIVED AT
CAPE SARICHEF, ALASKA
21 MAY 1962

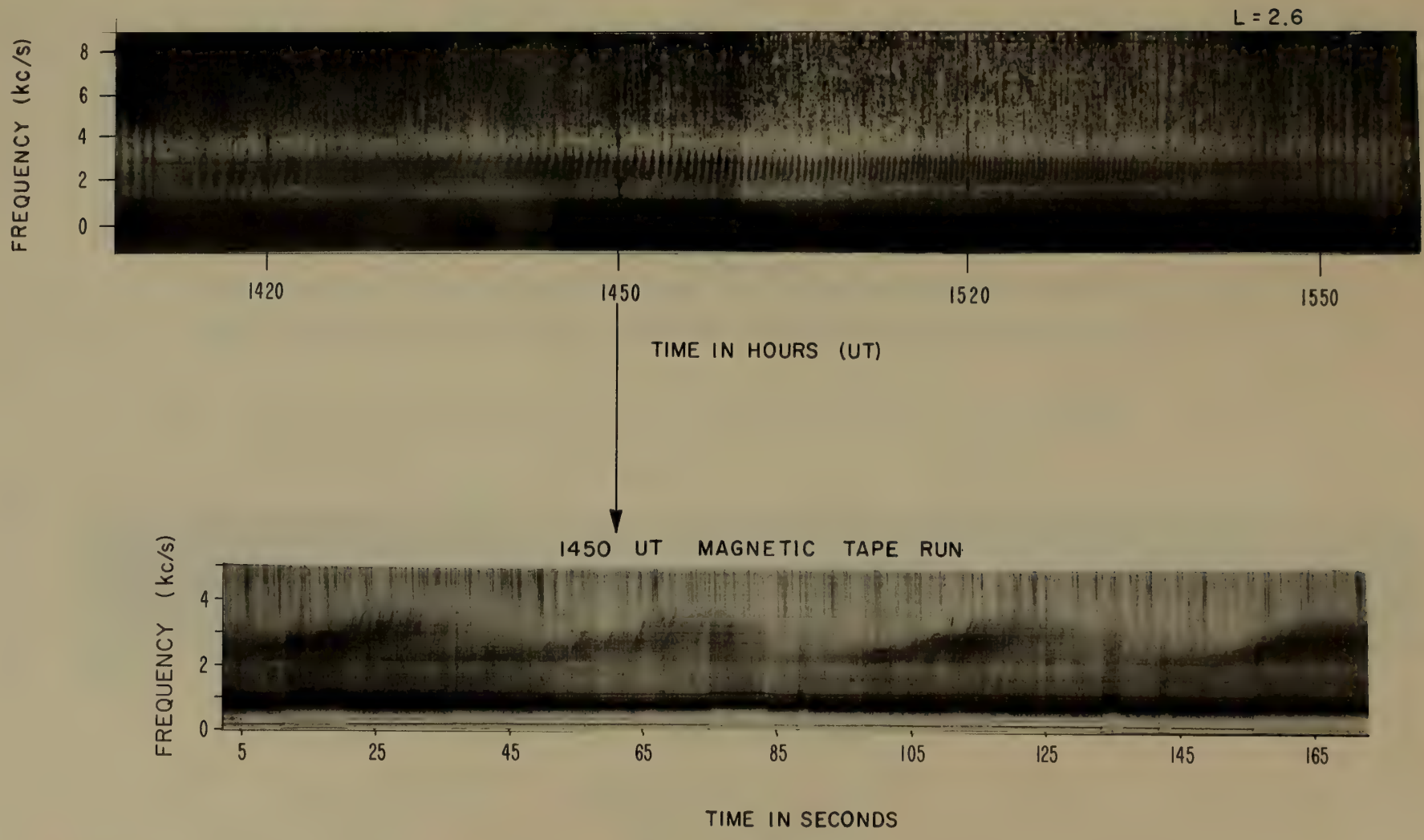


Figure 4.2 Intense, short-lived burst of long period VLF pulsations.

Pulsations with a period of 56 seconds were recorded at Minneapolis (L = 3.2) on 21 December 1962. Two of the pulsations were recorded on magnetic tape at 1250 UT. A group of whistlers can be seen between 6 and 10 kc/s in both.

Figure 4.2

VLF PULSATIONS RECEIVED AT
MINNEAPOLIS, MINN.
21 DECEMBER 1962

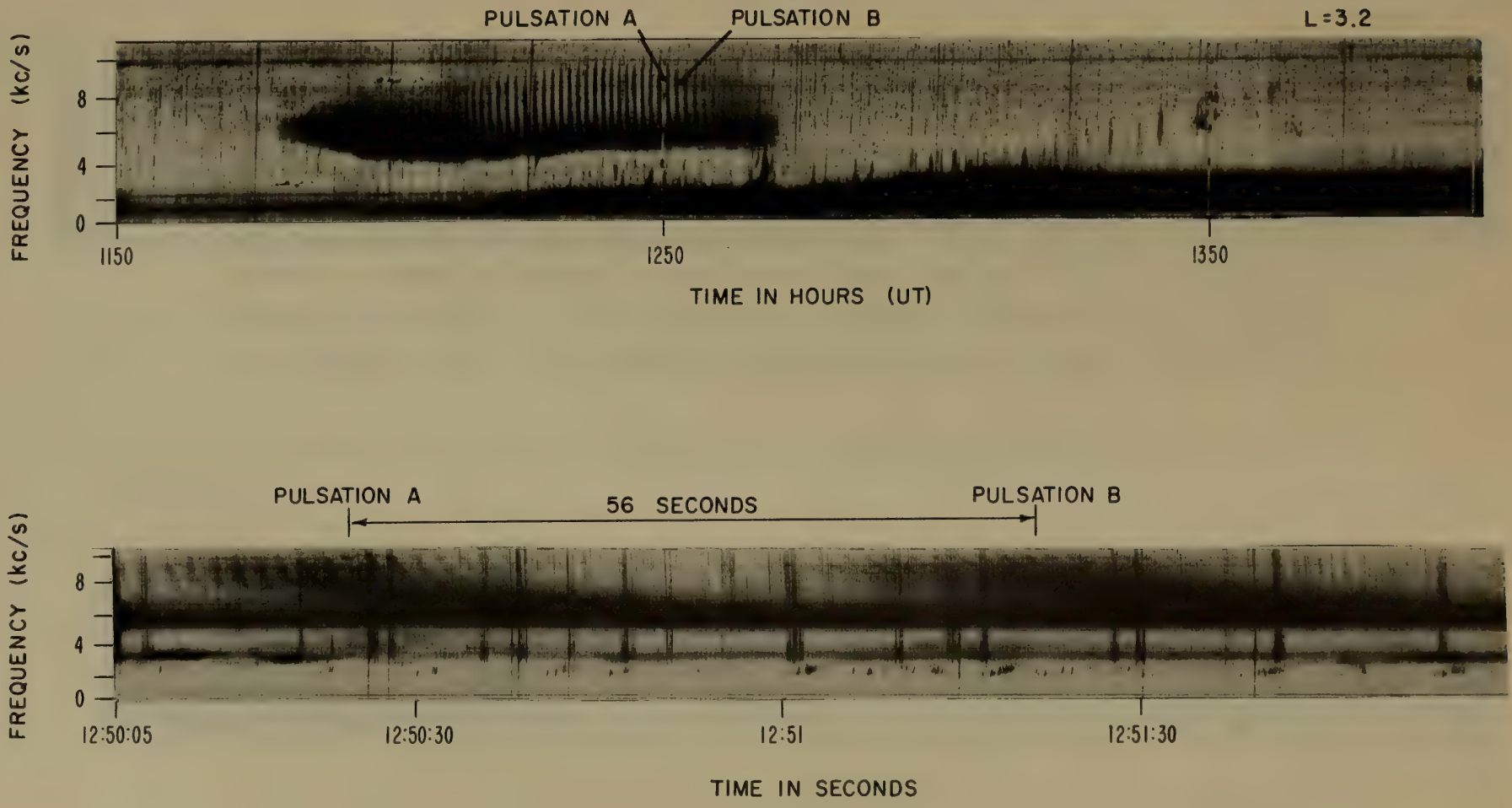


Figure 4.3 Long period VLF pulsations lasting for three hours.

On 1 February 1963 VLF pulsations of various periods were observed during three hours at Minneapolis (L = 3.2). At 0450 UT four were recorded on magnetic tape. They are composed of hiss and rising tones having a period of about 25 seconds.

Figure 4.3

VLF PULSATIONS RECEIVED AT
MINNEAPOLIS, MINN.
1 FEBRUARY 1963

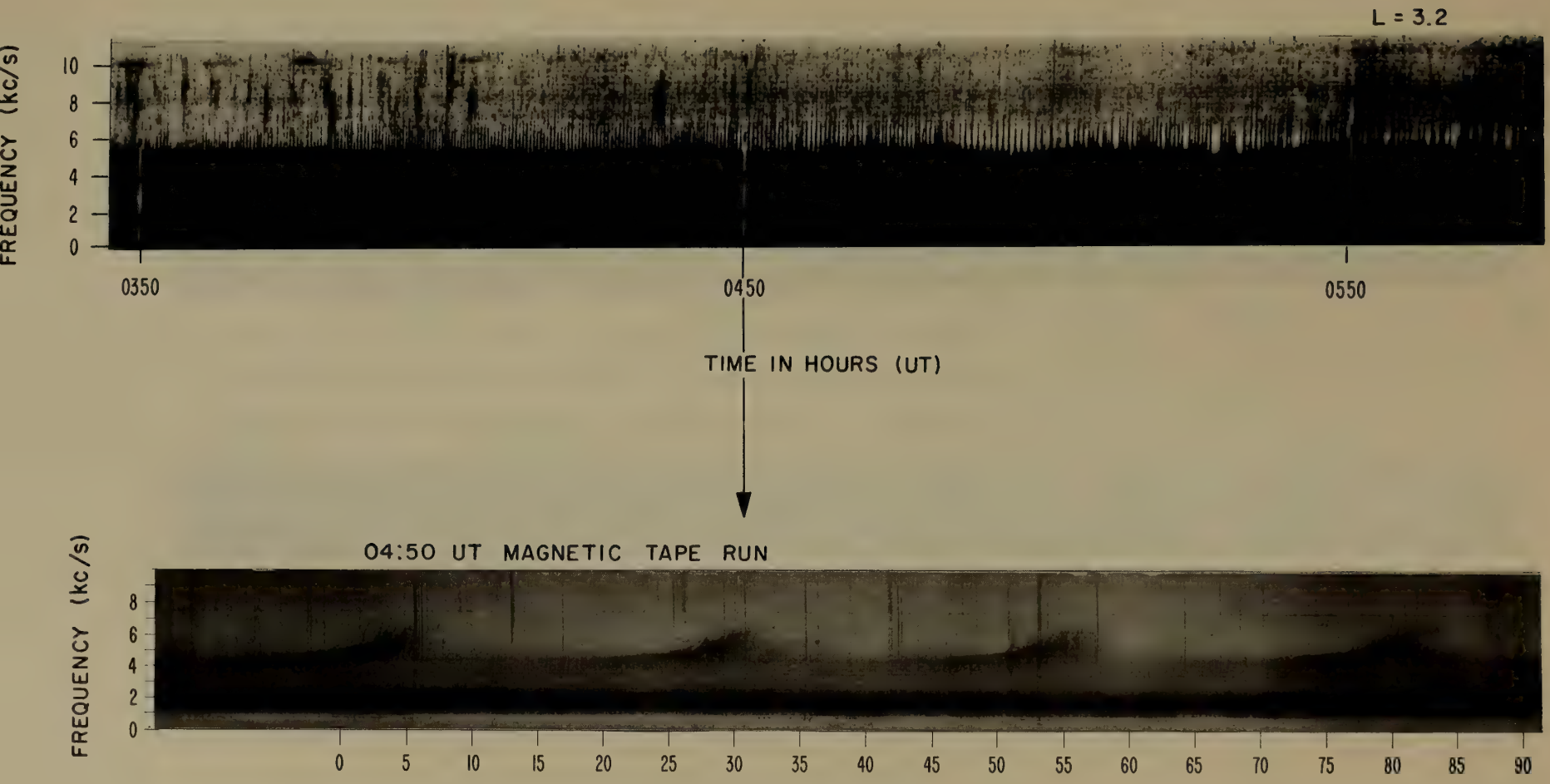
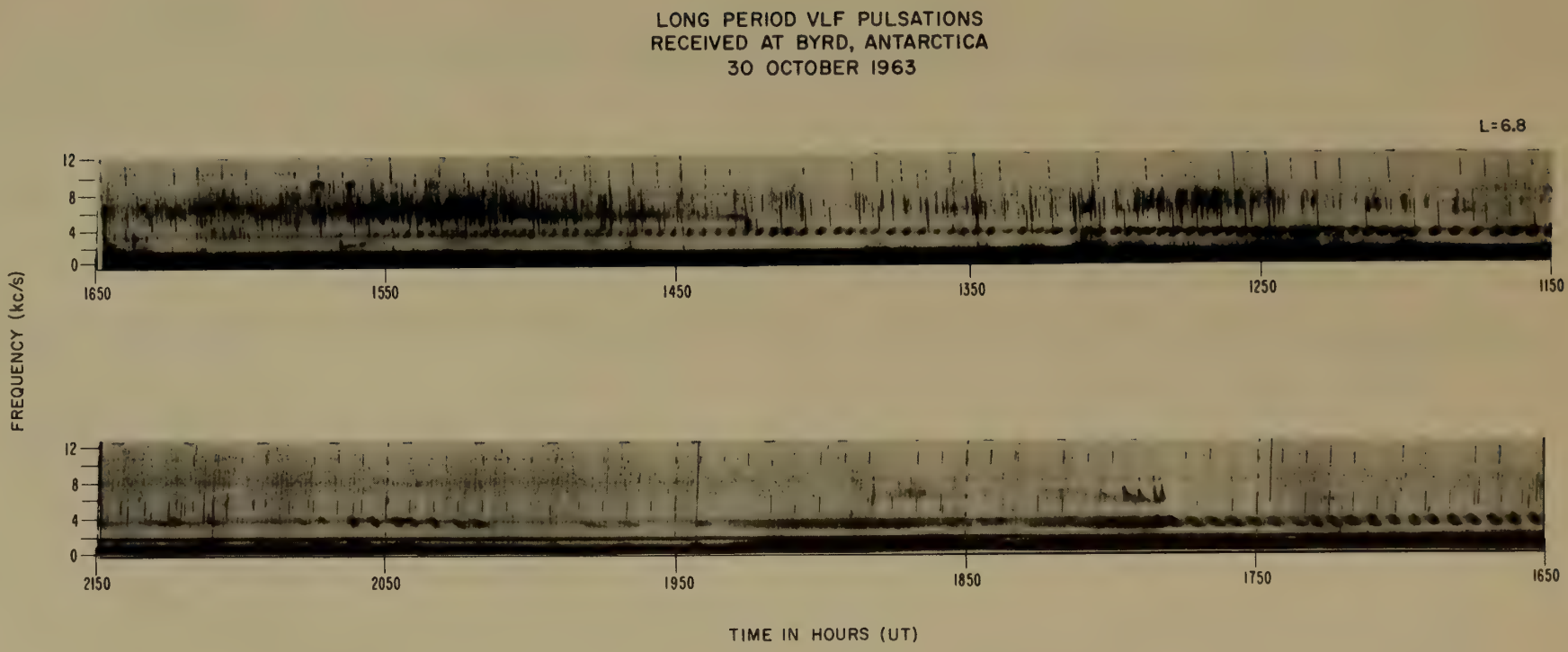


Figure 4.4 Nine hours of strong well-defined long period VLF pulsations.

VLF pulsations were recorded for nine hours on 30 October 1963 at Byrd Station. The frequency-time spectral shapes of these bursts are different from any others previously recorded at any latitude. At 1250 UT the period is about 120 seconds. At 1750 UT it is more than 200 seconds. The seven pulsations around 2050 UT are more than 240 seconds apart.

Figure 4.4


LONG PERIOD VLF PULSATIONS
RECEIVED AT BYRD, ANTARCTICA
30 OCTOBER 1963
L=6.8
FREQUENCY (kc/s)
12
8
4
0
1650
1550
1450
1350
1250
1150
2150
2050
1950
1850
1750
1650
TIME IN HOURS (UT)

APPENDIX

Station	L-value	Dates of hiss recorder operation
Boulder, Colorado	2.3	October 1961 to present
Cape Sarichef, Alaska } conjugate Waimate, New Zealand }	2.6	May 1962 to present
Minneapolis, Minnesota	3.2	May 1961 to present
Baie St. Paul, Quebec, Canada } conjugate Eights, Antarctica }	4.0	November 1961 to February 1962 and February 1963 to present
Great Whale River, Quebec, Canada } conjugate Byrd, Antarctica }	6.8	February 1963 to October 1963

ACKNOWLEDGMENT

The authors gratefully acknowledge the invaluable assistance of Messrs. D. H. Ashley and Kevin Ashley; Robert Nelson and Alvar Peterson; David Lewis; Lorne Matheson and Stefan Maagoe; Donel Frazer and Warner Ecklund; Reid Watson and Wayne McMurtry; T/Sgt. M. Davis, S/Sgt. Leon Johnson and T/Sgt. F. Wessel for their operation and maintenance of the stations at Waimate, New Zealand; Minneapolis, Minnesota; Byrd, Antarctica; Eights, Antarctica; Baie St. Paul, Quebec; Great Whale River, Quebec; and Cape Sarichef, Alaska, respectively.

REFERENCES

Anderson, K. A., C. D. Anger, R. R. Brown and D. S. Evans (1962), Simultaneous electron precipitation in the Northern and Southern auroral zones, J. Geophys. Res. 67, 4076-4077.

Brice, N. M. (1962), Discussion of paper by R. L. Dowden, 'Doppler-shifted cyclotron radiation from electrons: A theory of very low frequency emissions from the exosphere', J. Geophys. Res. 67, 4897-4899.

Brice, N. M. (1963), An explanation of triggered VLF emissions, J. Geophys. Res. 68, 4626-4628.

Dinger, H. E. (1956), Whistling Atmospherics, NRL Report No. 4825, September 14, 1956.

Dinger, H. E. (1957), Periodicity in dawn chorus (abstract), IRE Trans. Antennas Prop. 5, 325.

Gallet, R. M. and D. L. Jones, A systematic classification of natural VLF noises other than whistlers, presented at URSI Spring Meeting, May 1957.

Helliwell, R. A. and D. L. Carpenter (1961), Whistlers-West IGY-IGC synoptic program, final report NSF. IGY 6.10/20 and G-8839, Radioscience Laboratory, Stanford University, March 20, 1961.

Helliwell, R. A., J. P. Katsufrakis, K. E. Marks, D. Reed, M. L. Trimpi (1962), An atlas of selected VLF spectra from Byrd Station, Antarctica, NSF 9511, 13465, 17217, Radioscience Laboratory, Stanford University, March 15, 1962.

Helliwell, R. A. (1963), Whistler-triggered periodic very-low-frequency emissions, J. Geophys. Res. 68, 5387-5395.

Hook, J. L. (1962), Some observations of ionospheric absorption at geomagnetic conjugate stations in the auroral zone, J. Geophys. Res. 67, 115-122.

Jones, D. L., R. M. Gallet, J. M. Watts and D. N. Frazer (1963), An atlas of whistlers and VLF emissions, a survey of VLF spectra from Boulder, Colorado, NBS Technical Note, No. 166.

Leinbach, H. and R. P. Basler (1963), Ionospheric absorption of cosmic radiation noise at magnetically conjugate auroral zone stations, J. Geophys. Res. 68, 3375-3382.

Little, C. G., E. R. Schiffmacher, H. J. A. Chivers, K. W. Sullivan (1964), Cosmic noise absorption events at geomagnetically conjugate stations. Submitted for publication.

Lokken, J. E., J. A. Shand, S. C. Wright, L. H. Martin, N. M. Brice and R. A. Helliwell (1961), Stanford-Pacific Naval Laboratory conjugate point experiment, Nature 192, 319-320.

McIlwain, C. E. (1961), Coordinates for mapping the distribution of magnetically trapped particles, J. Geophys. Res. 66, 3681-3691.

Pope, J. H. and W. H. Campbell (1960), Observations of a unique VLF emission, J. Geophys. Res. 65, 2543-2544.

Watts, J. M., J. A. Koch and R. M. Gallet (1963), Observations and results from the "hiss recorder", an instrument to continuously observe the VLF emissions, J. Research NBS 67D (Radio Prop.) No. 5, 569-579.

GPO 845-368


DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA